AD NUMBER

AD492626

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; 01 MAR 1949. Other requests shall be referred to Army Medical Research Laboratory, Fort Knox, KY.

AUTHORITY

USAMRL ltr, 26 Feb 1970

[ME]DICAL DEPARTMENT

FIELD RESEARCH LABORATORY

Fort Knox, Kentucky

PROJECT NO. 6-64-12-06
M.D.F.R.L. NO. 6-64-12-06-(7)
Submitted 1 March 1949

Report #22

PULSATILE EVAPORATIVE RATES FROM SMALL SKIN AREAS

AS MEASURED BY AN INFRARED GAS ANALYZER*

*Sub-project under Studies of Body Reactions and Requirements under Varied Environmental and Climatic Conditions. Approved 31 May 1946. M.D.F.R.L. Project No. 6-64-12-06-(7).

6

PULSATILE EVAPORATIVE RATES FROM SMALL SKIN AREAS AS MEASURED BY AN INFRARED GAS ANALYZER,*

by

10

Roy E. Albert, [redacted] E. D. Palmes [redacted]

from

Medical Department Field Research Laboratory
Fort Knox, Kentucky

11 1 Mar [redacted] 49

12 13p.

*Sub-project under Studies of Body Reactions and Requirements under Varied Environmental and Climatic Conditions. Approved 31 May 1946. M.D.F.R.L. Project No. 6-64-12-06-(7).

16 MDFRL-6-64-12-06-(7)

(039 650)

Project No. 6-64-12-06
Sub-project MDFRL 06-(7)
MEDEA

1 March 1949

ABSTRACT

PULSATILE EVAPORATIVE RATES FROM SMALL SKIN AREAS AS MEASURED BY AN INFRARED GAS ANALYZER

THE OBJECT OF THIS RESEARCH IS

To study the characteristic evaporative patterns from small skin areas and to determine the significance of the observed fluctuations in evaporative rate in terms of sweat secretion.

RESULTS AND CONCLUSIONS

A. The evaporative rates from small skin areas were studied on 2 subjects using a Leeds and Northrup selective infrared gas analyzer, modified for the determination of water vapor. The evaporative rates were obtained by passing dry oxygen through a cup on the skin and then to the analyzer in a closed circuit where the concentration of water vapor in the carrier gas was continuously recorded.

B. Four evaporative patterns were observed corresponding to particular ranges of local evaporative water loss, expressed as percentages of the highest observed rates:

1. In the range of 2-5%, no significant rate pulsations were noted.

2. In the range of 5-15%, the rate pulsations occurred sporadically.

3. In the moderate range, between 15-90%, the pulsations occurred continuously, averaging 6-7 peaks per minute with a standard deviation of approximately 2.0.

4. At maximal rates, observed only on the forehead and trunk, the frequency and amplitude of the pulsations decreased and the tracing approached a straight line.

C. It was found, using duplicate sets of equipment, that the pulsations from several skin areas, in the same evaporative range, occurred almost simultaneously. This suggested that many of the sweat glands were excited by a common stimulus, possibly central in origin.

D. Of the various factors that could produce pulsatile variations in the evaporative rate under constant ambient conditions with the subject at rest, it was determined that only the fluctuations in the wetted area were significant. The measurements were not related to individual sweat gland activity.

E. The ideal instrument for the method would be one whose capacity and response time were negligible factors when measuring rapid changes in water vapor concentrations. This was not the case with the instrument used in these experiments.

RECOMMENDATIONS

None.

Submitted by:
R. E. Albert, Capt., M.C.
E. D. Palmes, Ph.D.

Approved Ray G. Daggs
RAY G. DAGGS
Director of Research

Approved Frederick J. Knoblauch
FREDERICK J. KNOBLAUCH
Lt. Col., M.C.
Commanding

PULSATILE EVAPORATIVE RATES FROM SMALL SKIN AREAS
AS MEASURED BY AN INFRARED GAS ANALYZER

I. INTRODUCTION

Although there is evidence that sweat production, under steady ambient conditions from small skin areas, is fluctuant, no method has yet been available to make a critical study of this finding. Randall (1), using a colorimetric technique, reported cyclic variations in the number of active sweat glands in the hands. Burch et al. (2) using a method in which sweat from the fingers and toes was evaporated and weighed, reported a considerable variation in the evaporative loss from one collecting period to the next. The measurements in both methods, however, were periodic.

At this laboratory, a Leeds and Northrup selective infrared gas analyzer has been used for determining the evaporative rates from the whole man. Because the method afforded continuous as well as quantitative measurements, it could be used to determine the frequency and magnitude of the evaporative rate fluctuations with greater accuracy than other existing methods. The apparatus was, therefore, modified and used to study: (1) the characteristic evaporative patterns from small skin areas; (2) the significance of the evaporative rate fluctuations in terms of sweat gland activity.

II. EXPERIMENTAL

A. Apparatus and Methods

Since the infrared gas analyzer measures only the concentration of water vapor in its analysis cells, the measurements, to be of significance in terms of sweat production, must be related to conditions on the skin surface. The factors which can produce variations in the evaporative rate (4) are: variations in the velocity and direction of the air flow over the skin, in the temperature and salt concentration of the sweat, and in the percentage of the skin area that is wet. It will be shown in the following experiments that only the variations in wetted area of the skin were significant in the production of the observed evaporative rate pulsations.

1. Description of the Apparatus (Figure 1).

A Leeds and Northrup selective infrared gas analyzer, modified by Palmes for the measurement of water vapor (3), contains a partitioned analysis chamber in which the water vapor concentration of one side is compared with that of the other and the difference recorded continuously on the strip chart of a milliammeter. A metal cup, 20 square centimeters in cross-sectional area, was placed on the skin and dry oxygen passed through it from one compartment of the analysis chamber. As it passed through the cup, the sweat on the skin was evaporated and the moist oxygen then went to the other compartment. The dry oxygen was supplied from an oxygen tank and the flow rate was maintained constant as determined by an orifice flow meter. The cup was connected to the gas analyzer by fixed lengths of rubber tubing.

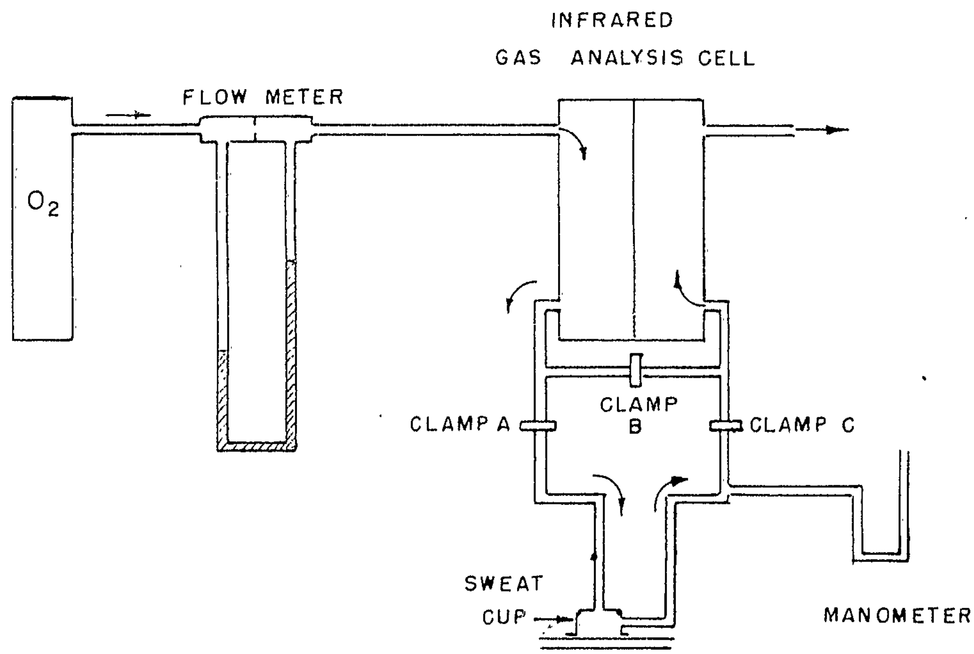

FIG. 1 SCHEMATIC DIAGRAM OF APPARATUS

When the cup to skin seal was broken, there was an immediate drop in pressure recorded by a manometer connected to one of the tubes. When the instrument base line was to be adjusted, a brass plate was clamped to the cup, or clamps A and C were closed and clamp B opened. The latter method allowed a base line adjustment to be made without removing the cup from the skin. An oxygen flow rate of 3 liters per minute was used in all experiments because it was found empirically to be sufficient to evaporate all the sweat that appeared under the cup and low enough to insure adequate sensitivity.

2. Calibration of the Apparatus.

a. Sensitivity of the Instrument to Water Vapor: This calibration related the concentration of water vapor in the analysis cell to the recorded deflection. It was accomplished by introducing various measured flow rates of saturated oxygen through the brass plate clamped to the bottom of the cup. The saturated oxygen mixed with the dry gas flowing through the system and the concentration of water vapor could then be calculated and compared to the deflection. The relationship of water vapor concentration to deflection in the range of 0 to 1% was linear and the slope equaled 40 microvolts per 1% water vapor. The full scale of the instrument was 100 microvolts. The drift was small and linear and corrections for it were easily made.

b. Sensitivity of the Instrument to Wetted Area: This calibration was done to relate the concentration of the water vapor in the analysis cell to the percentage wetted area under the cup. Six circular pits of various diameters were drilled into one face of a smooth plastic block with adequate space between to accommodate the cup. The pits were filled with distilled water and the level adjusted to the same height in each case. The temperature of the water was kept at $35^{\circ} \pm 1^{\circ}C$. The cup was first placed on a dry area next to the pit and a base line deflection was recorded. Next, the cup was slid onto the pit and held there until the deflection attained a constant level; then the procedure was reversed. This was done for each pit. At a temperature of $35^{\circ}C.$, in the range of 0 to 10% wetted area, it was found that a 1% wetted area was equivalent to approximately 5 microvolts deflection and that this relationship was linear. Since the deflections were constant independent of the position of the cup, it was concluded that there were no significant eddy currents within the sweat cup, and since the manometer level of the orifice flow meter was always steady, the convective load on the skin was considered constant.

c. Effect of Temperature of the Wetted Area: In order to evaluate the effect of temperature fluctuations on variations in evaporative rate, the following calibration was done: One of the holes described above was selected and the same procedure carried out except that the temperature of the water was adjusted in 5 degree steps from $20^{\circ}C.$ to $40^{\circ}C.$ It was found that with a constant wetted area, a variation of 2 degrees within this temperature range was equivalent to a change of approximately 1 microvolt deflection. This demonstrated that fluctuations such as normally occur about a constant average skin temperature would produce an insignificant physical effect on the evaporative rate.

d. Effect of the Concentration of Sodium Chloride in the Sweat: The vapor pressure of a saturated solution of sodium chloride, in the range of skin temperature, is only a few millimeters of mercury lower than that of distilled water. If the concentration of salt in the sweat had a significant effect, it would be cumulative, and the average evaporative rate would decrease gradually. Since this was not the case in these experiments, it was considered that this effect was negligible.

e. Response Time of the Instrument: The lag in response due to conduction of water vapor through the rubber tubing was measured by placing the sweat cup over a wetted area and noting the delay until the initial change of deflection on the recording milliammeter. This was 2 to 3 seconds.

A determination of the 90% response time of the thermopile, (the 90% being an arbitrary figure), was done by quickly chopping the optical path with a trimmer screw. The response time was 6 to 7 seconds and was independent of the degree of narrowing of the optical path. A measurement of the 90% response time of the apparatus to an increase in wetted area was accomplished by placing the cup over a wetted area and measuring the time elapsed until the 90% deflection occurred, allowing for the lag due to conduction through the leads. This was demonstrated to be equal to the values obtained by mechanically chopping the optical path. However, the 90% response time to decrease in wetted area was uniformly 3 to 4 seconds longer than that of the increase. This difference represented the 90% clearance time of the system. Since these response times were independent of the amount of change in per cent wetted area, the slopes of the deflections were directly related to the change in wetted area. Note that in Figure 2, the slopes a, b, c, and d are functions of the change in concentrations a′, b′, c′, and d′.

The maximal detectable frequency of change in wetted area depended on the magnitude of the change. By sliding the sweat cup on and off a wetted area, the largest detectable frequency of a particular change of wetted area could be determined. Thus, a change of 16% wetted area permitted a maximum of 30 evaporative rate peaks per minute, and of 3% wetted area, 15 evaporative rate peaks per minute.

It is, therefore, apparent that the instrument detects initial changes in water vapor concentration immediately. However, changes more rapid than every 8 seconds are damped, but a minimum value for these changes can be calculated from the slope of the response.

3. Experimental Procedure

An analysis of the method has been made, and it has been demonstrated that the recorded variations in evaporative rate in this method were due solely to the variations in wetted skin area. These, in turn, were dependent on the activity of the sweat glands. The following experiments deal with some of the characteristics of the evaporative rate pulsations

All experiments were performed on 2 subjects in a hot room. The subjects were equilibrated to the particular ambient temperature for one-half hour, lying on a fiber net. The equilibration time was based

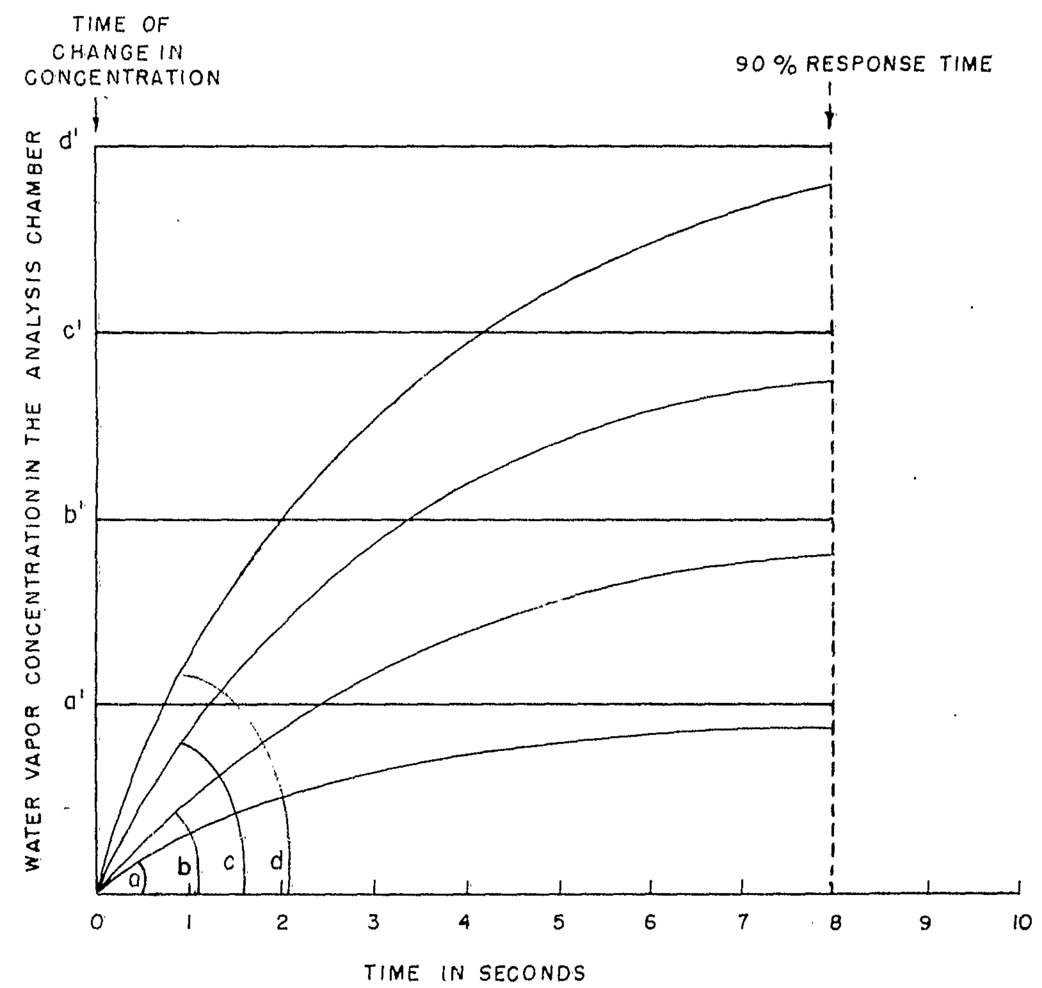

FIG. 2 INSTRUMENT RESPONSE TO INSTANTANEOUS CHANGES IN WATER VAPOR CONCENTRATION

on the work of Adolph (5), in which the average evaporative rate of a resting man plateaus in 15 to 20 minutes following exposure to a higher ambient temperature.

B. Results

1. Typical Evaporative Patterns at Various Ambient Temperatures.

When the 4 tracings of Figure 3 are compared with each other, the following essential differences will be noted. Figure 3A was characteristic of the evaporative pattern obtained from all skin areas when the subject was in the zone of vasomotor control (6), that is, between the ambient temperatures of 23° to 31°C. The evaporative rate was recorded as a 1-2 microvolt deflection with no significant pulsations. This probably represented insensible water loss. However, at somewhat higher ambient temperatures, some skin areas showed evaporative patterns illustrated by Figure 3B and others continued with the pattern of 3A. The former pattern was characterized by intermittent rate pulsations, which occurred sometimes singly and sometimes in groups. This was probably caused by intermittent sweat gland activity. Figure 3C represents the moderate evaporative rates which occurred between the very low and near maximum levels. The pattern is one of continuous pulsatile variation.

When the evaporative rate became very high, (Figure 3D), the frequency and amplitude of the rate variations decreased and the tracing tended to become a straight line. This was observed only on the trunk and forehead. This was not caused by flooding of the skin with sweat because the actual deflections were in the range of 8-10% wetted skin area.

The very high evaporative rates were produced in these experiments by exposure to an ambient temperature of 51°C. and 20% humidity, high exercise rates at 43°C. or water baths at 40°C.

Considering the highest observed evaporative rates (40-45 microvolts) as 100%, the minimal constant evaporative rates were in the range of 3-5%, and the range of sporadic evaporative pulsations was 5-15%. It was not possible to determine whether there was any sweat gland activity at the minimal evaporative rates.

It was not necessary to establish a precise relationship of the local and total evaporative loss because the various skin areas did not necessarily sweat under the same heat load. However, once the activity was established, there was a close correlation between the ambient temperature and the evaporative loss from a cup site.

A 2 minute section of the record obtained on a resting subject at 43°C. was reconstructed in Figure 4 with the evaporative rates calculated from the slopes of the obtained tracing. This procedure involved the assumption that the evaporative rates change instantaneously. This assumption produced minimal values for the change of rate. It will be noted that the evaporative rate fluctuated markedly, in this instance, 38 times in 2 minutes. The average change was approximately 25% of the highest obtained evaporative rates in these experiments.

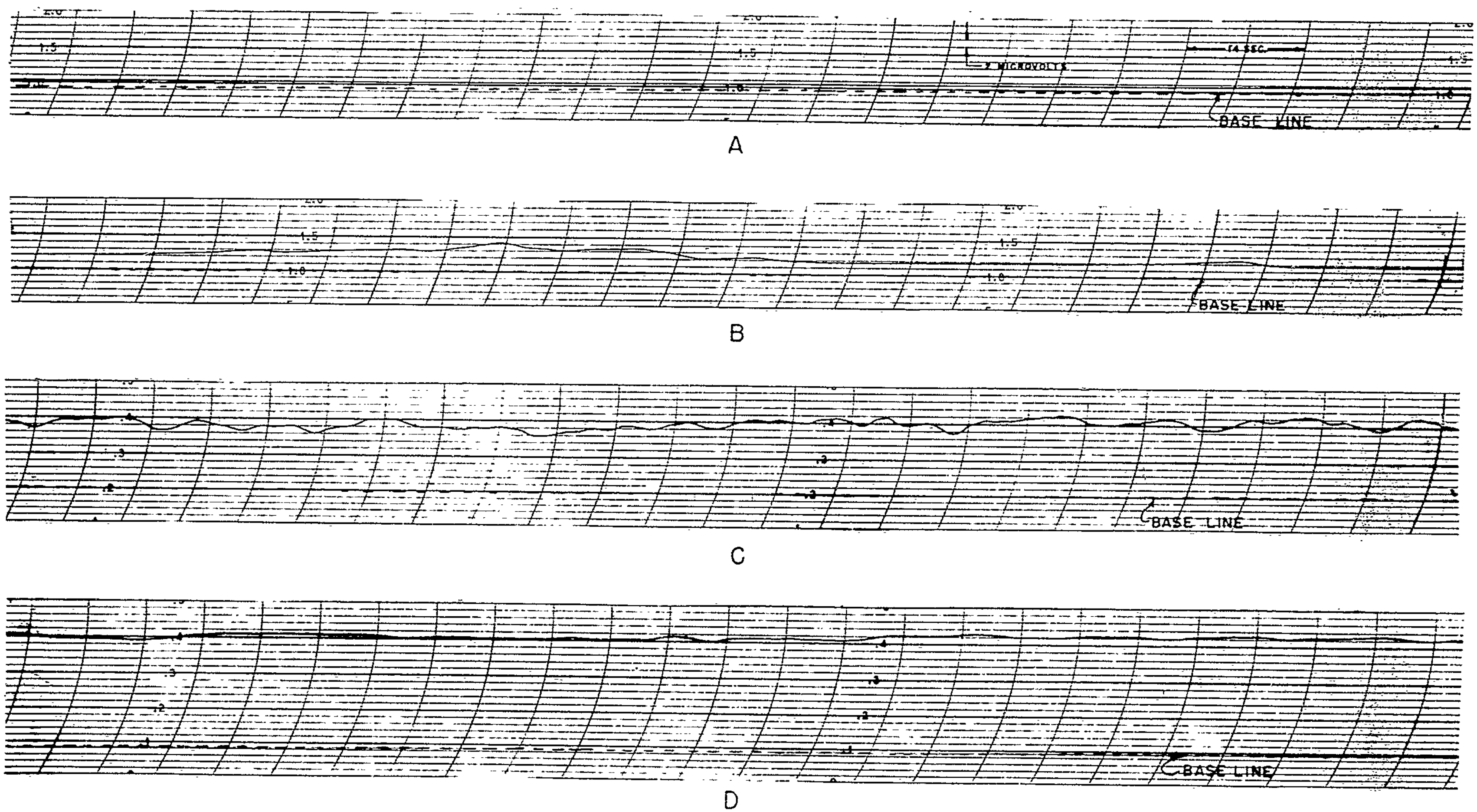

FIG. 3 TYPICAL EVAPORATIVE PATTERNS

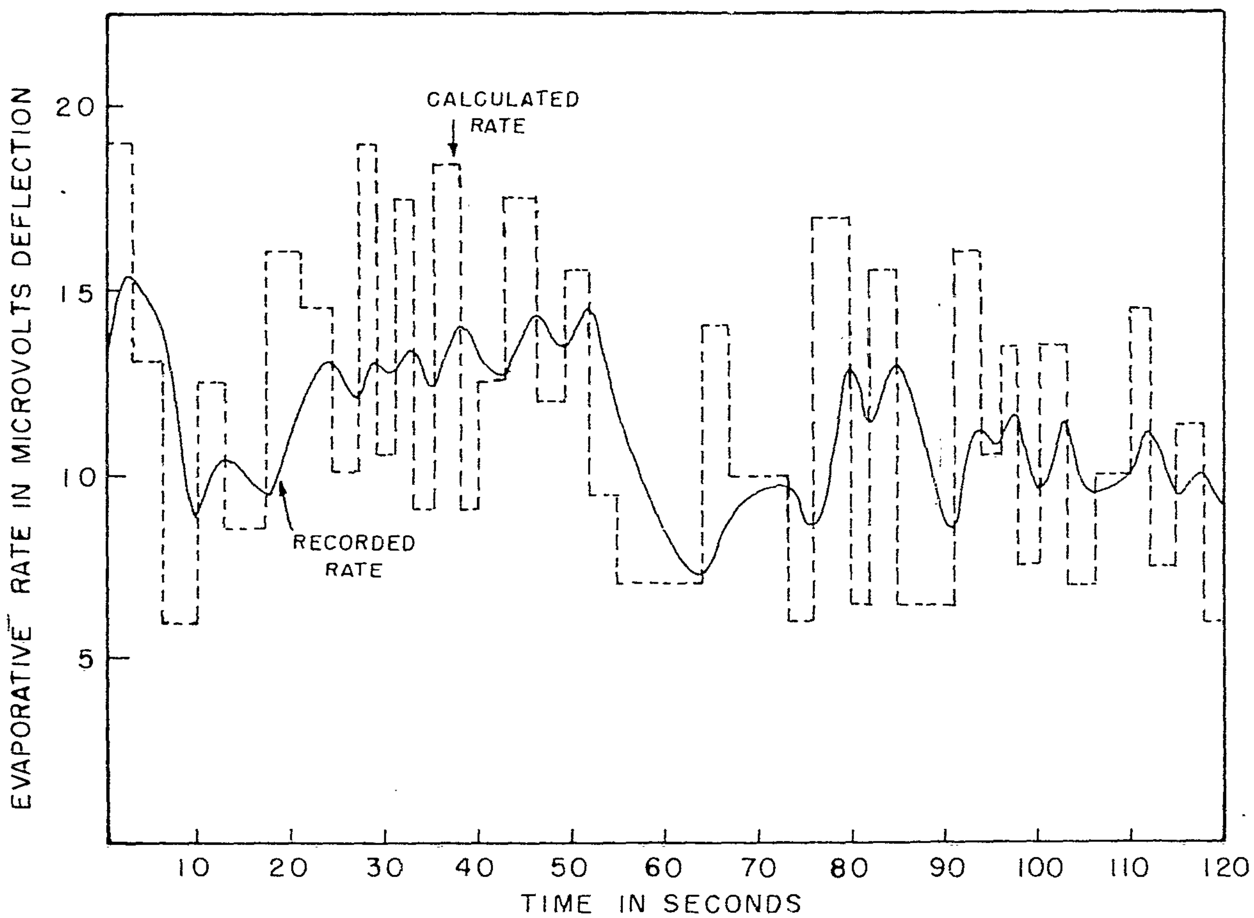

FIG. 4. SERIAL EVAPORATIVE RATE CHANGES

An analysis of 6 runs, with evaporative rates in the moderate ranges, showed that there was no correlation between the evaporative slopes or the frequency of peaks per minute with the average local evaporative rate or the ambient temperature. However, there was a good correlation between the ambient temperature and the average local evaporative rate. It was apparent from this analysis, that in the range of the moderate evaporative rates, the average evaporative water loss from the cup site changed without any change in frequency or amplitude of the rate pulsations.

A histogram of the occurrence of the number of evaporative peaks per minute in the moderate range was drawn up on each of the 2 subjects. Figure 5 is an example of one of them. The mean frequency of both subjects was between 6-7 evaporative peaks per minute and the standard deviation in both was approximately the same (1.5 - 2.0).

2. The Simultaneous Measurement of Dissimilar Skin Areas

The subject was seated on a stool, equilibrated to an ambient temperature of 43°C. at 20% humidity. Duplicate sets of equipment were used to obtain simultaneous evaporative rates from various skin areas. Chart speeds were synchronized so that one record could be traced over the other.

Damage to one set of equipment restricted the experiment to 6 runs on one subject. However, from adjacent areas of the forehead and the back, forehead-back, back-chest, both palms, back-thigh, the evaporative rates from both skin areas tracked along almost simultaneously (Figure 6). The average local evaporative rate from these areas was in the moderate range. The amplitude of the recorded rate variations in this experiment was larger than in the other experiments because of the difference in instrument sensitivity. The dotted curve in Figure 6A and the lower curves in Figures 6B and 6C were traced in.

III. DISCUSSION

Infrared gas analysis is an accepted technique for the determination of water vapor. Therefore, the results, as measurements of water vapor concentrations, were valid within the stated limits of sensitivity. The important consideration for this report is to define the relationship of these results to sweat gland activity.

It has been demonstrated that under the conditions of these experiments the fluctuations in evaporative rate were dependent only on the fluctuations in the percentage wetted area of the skin under the cup. However, this in turn, depended on two variables: (1) the number of actively sweating glands, and (2) the quantitative output of each of them. Therefore, no direct relationship could be established between wetted area and individual sweat gland activity. However, if the glands discharged randomly, the evaporative rate would tend to be constant because of the large number of glands (more than 100 (7)) under the cup. Since the measured variations in evaporative rate were often very large, it was possible that a considerable number of glands were discharged at about the same time. This possibility was strengthened by the fact that these variations were almost simultaneous in dissimilar areas of the skin; suggesting a central mechanism that excited

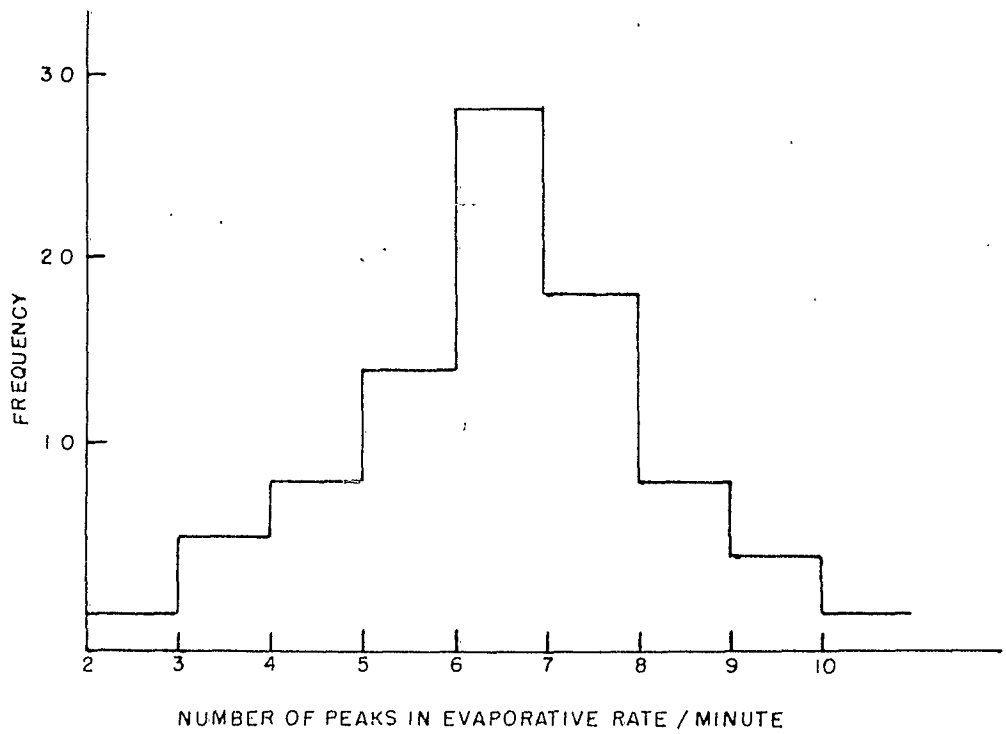

FIG. 5 HISTOGRAM OF EVAPORATIVE RATE PEAKS PER MINUTE ON A RESTING EQUILIBRATED SUBJECT

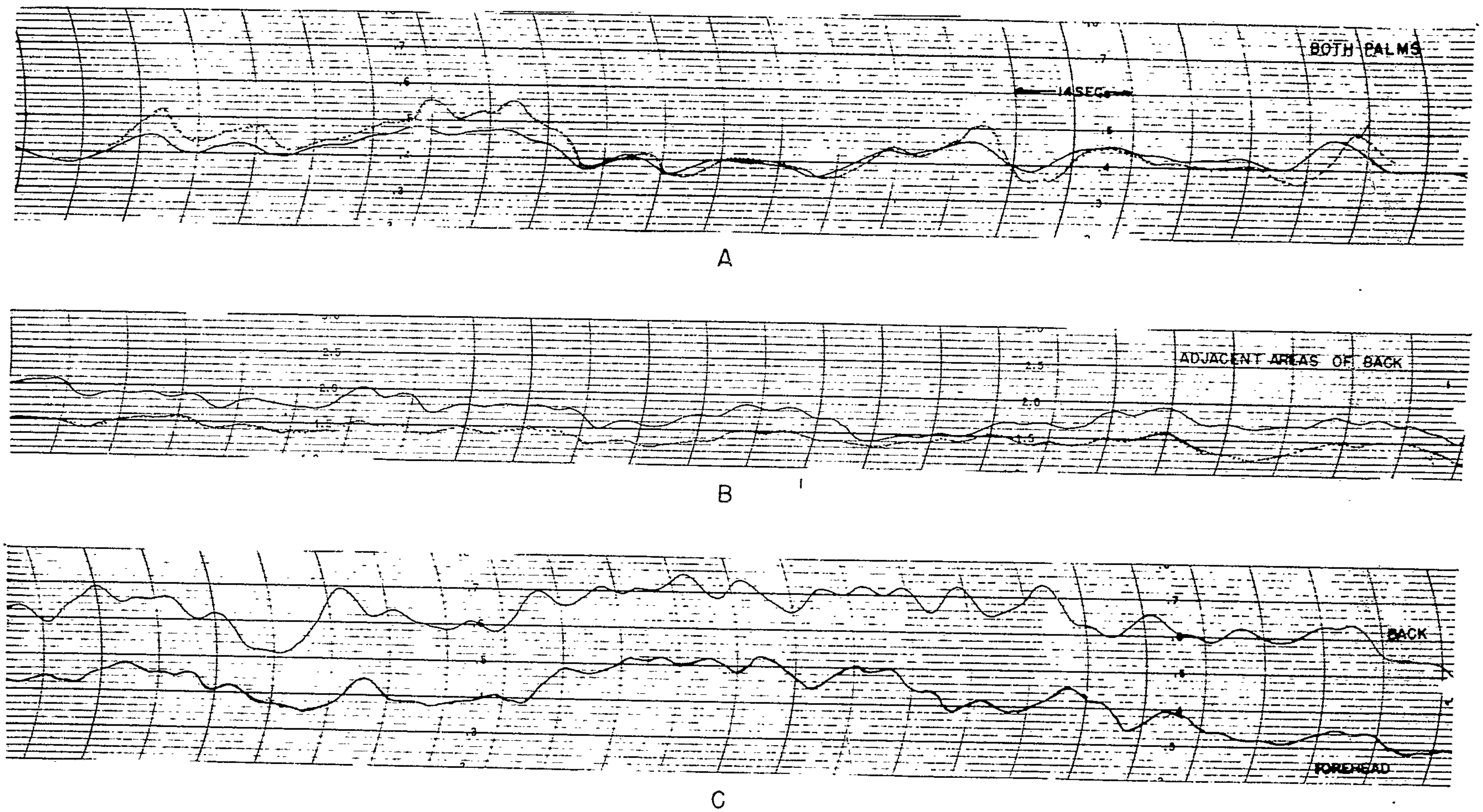

FIG. 6 SIMULTANEOUS EVAPORATIVE RATES

many or all the glands at once.

The pulsations described with this method have an essential difference from those described by Randall (2) who used a colorimetric technique. He quantitated the number of discharging glands, whereas this method quantitated the output of the glands within the cup area. Only infrequently were cycles seen which lasted several minutes such as described by Randall, and these occurred at moderately low evaporative rates.

The particular gas analyzer used for this work has certain characteristics which limit its usefulness. The ideal instrument would be one in which the capacity of the system and the response time were negligible factors when measuring small, rapid changes in water vapor concentration. Since the 90% response time of this instrument is 8 to 10 seconds, rate variations, whose duration was shorter than this period of time, were reproduced in a distorted fashion. As has been demonstrated, the maximal detectable frequency of change depended on the magnitude of the variation in water vapor concentration. Therefore, it was possible that larger frequencies in change of evaporative rate existed but were lost because the magnitude of the variation was too small.

The gas flow through this system should have been high enough to evaporate all the water as it appeared on the skin. Since no beading of sweat was observed under the cup at the termination of the experiments, this was probably the case. It was not possible to determine the effect of the relatively high convective load within the cup on the local evaporative rate, or the effect of the occlusion of some of the skin circulation by the rims of the cup. However, the method was standard for all experiments and, therefore, a comparison of results was valid.

IV. SUMMARY AND CONCLUSIONS

A. The evaporative rates from small skin areas were studied on 2 subjects using a Leeds and Northrup selective infrared gas analyzer, modified for the determination of water vapor. The evaporative rates were obtained by passing dry oxygen through a cup on the skin and then to the analyzer in a closed circuit, where the concentration of water vapor in the carrier gas was continuously recorded.

B. Four evaporative patterns were observed corresponding to particular ranges of local evaporative water loss, expressed as percentages of the highest observed rates:

1. In the range of 2-5%, no significant rate pulsations were noted.

2. In the range of 5-15%, the rate pulsations occurred sporadically.

3. In the moderate range, between 15-90%, the pulsations occurred continuously, averaging 6-7 peaks per minute with a standard deviation of approximately 2.0.

4. At maximal rates, observed only on the forehead and trunk, the frequency and amplitude of the pulsations decreased and the tracing approached a straight line.

C. It was found, using duplicate sets of equipment, that the pulsations from several skin areas, in the same evaporative range, occurred almost simultaneously. This suggested that many of the sweat glands were excited by a common stimulus, possibly central in origin.

D. Of the various factors that could produce pulsatile variations in the evaporative rate under constant ambient conditions with the subject at rest, it was determined that only the fluctuations in the wetted area were significant. The measurements were not related to individual sweat gland activity.

E. The ideal instrument for the method would be one whose capacity and response time were negligible factors when measuring rapid changes in water vapor concentrations. This was not the case with the instrument used in these experiments.

V. RECOMMENDATIONS

None.

VI. BIBLIOGRAPHY

1. Randall, W. C. Sweat gland activity and changing patterns of sweat secretion on the skin surface. Am. J. Physiol. 147: 391, 1946.

2. Burch, G. E., A. E. Cohn and C. Neumann. Study of the rate of water loss from surfaces of finger tips and toe tips of normal and senile subjects and patients with arterial hypertension. Am. Heart J. 23: 185, 1942.

3. Palmes, E. D. An apparatus and method for the continuous measurement of evaporative water loss from human subjects. Rev. Sci. Inst. 19: 711, 1948

4. Gagge, A. P. A new physiological variable associated with sensible and insensible perspiration. Am. J. Physiol., 120: 277, 1937.

5. Adolph, E. F. Initiation of sweating in response to heat. Am. J. Physiol. 145: 710, 1946.

6. Sheard, Charles. Temperature of the skin and thermal regulation of the body. In Glasser, Otto, Medical Physics. Chicago, Year Book Publishers, 1947, pages 1523-1555.

7. Kuno, Y. The physiology of human perspiration. London, J. & A. Churchill, Ltd., 1934.

UNCLASSIFIED

UNCLASSIFIED